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THE EFFECTS ON HEATHLAND AND MOORLAND SOILS IN SCOTLAND AND NORTHERN ENGLAND FOLLOWING COLONIZATION BY BIRCH (*BETULA* SPP.)

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SUMMARY

The paper summarizes the main findings of a study to examine the effects on Calluna *heathland soils in Scotland and northern England following colonization by birch* (Betula pendula *and* B. pubescens). *In the field layer,* Calluna *is initially replaced mainly by* Deschampsia flexuosa *and* Vaccinium myrtillus; *other species appear more gradually. The heathland mor humus gives way to mull, while pH, base status, rates of nitrogen mineralization and cellulose decomposition, and the growth response of test plants all tend to increase markedly. The methodological approach, mechanisms of soil change, and possible implications of the results to forestry are discussed.*

INTRODUCTION

Heathlands and moorlands are a significant natural resource in Britain, forming about 30 % of the land area (*c.* 7.2 Mha). They are especially important in Scotland, forming about 65 % of its land area (*c.* 5.0 Mha) (Ministry of Agriculture, etc., 1966; EDWARDS & WIBBERLY, 1971). They support several overlapping uses, in particular farming of sheep and cattle, cropping of red grouse (*Lagopus lagopus scoticus* Latham) and red deer (*Cervus elaphus* L.) for profit and sport, conservation of wildlife, and human recreation. Most have developed following the destruction of the former forest cover in historical and prehistorical times (DIMBLEBY, 1962; ANDERSON, 1967; GIMINGHAM, 1972). Persistant burning and grazing since then have prevented reinvasion by trees.

The most extensive vegetation types normally contain few vascular species. *Calluna vulgaris** was conservatively estimated to be the dominant species over at least 0.4 Mha in England and Wales and 1.2 Mha in Scotland a quarter century ago (DAVIES, 1942; GEDDES & STAMP, 1953), and is an important constituent of the vegetation over at least an equal area. There have since been losses due to afforestation and to conversion of grassland by farmers, but there are probably still at least 1.0 Mha of *Calluna* dominant heath in Scotland. The floristic poverty is partly a result of the inherently poor acid soils, but has probably been intensified directly by woodland destruction and subsequent grazing and burning (McVEAN & LOCKIE, 1969; GIMINGHAM, 1971), and indirectly by the acidifying effects of *Calluna* on the soil (GRUBB *et al.*, 1969; McVEAN & LOCKIE, 1969).

To increase wildlife diversity and to improve the quality of the grazings it is now often desirable to

* Vascular plant nomenclature follows CLAPHAM, TUTIN & WARBURG (1962).

introduce additional species to many sites, and to encourage their regeneration and spread. While experiments have shown that it is possible to establish many extra species from seed in *Calluna* heathland, it was also found that many species, including several that may have been present under former woodland conditions, established only if nutrients were added to the soil when seed was sown (DIMBLEBY, 1958; MILES, 1974, 1975).

The results of these introduction experiments led to a consideration of other, indirect ways in which soil fertility could be improved. *Calluna* heaths and moorlands typically bear mor humus over podzolized mineral horizons, which, apart from the nutrient deficiencies associated with the low pH values, contain substances inhibitory to germination and plant growth, and to mycorrhizal fungi and soil microorganisms (STEVENSON, 1966; ROBINSON, 1971; FUSTEC-MATHON *et al.*, 1975). There have however, been many suggestions that certain species, notably birch (*Betula pendula* and *B. pubescens*), are associated with mull formation in place of mor, and even with depodzolization (DIMBLEBY, 1952; HANDLEY, 1954; HUNTER, 1962; GARDINER, 1968). To replace *Calluna* heath by vegetation which would promote mull formation should permit edaphically more demanding species to establish in the long term, and thus develop the grazing value and wildlife diversity of the sites.

The reputation of birch as a soil "improver" seemed of particular potential importance. It is one of the most abundant trees in Britain, occupying about 13 % of all stocked woodlands (EDLIN, 1970). It is particularly abundant and important in the Scottish Highlands, where birch woods and scrub form a characteristic and attractive part of the landscape. These woods provide valuable browse and shelter for sheep and deer, firewood for man, are a potential source of pulpwood and timber, and support a rich fauna and flora compared with surrounding moorlands. However, despite a considerable literature, there is very little substantive evidence about the effects of birch on the soil.

Accordingly, a study was begun in late 1973 to identify the trends, rates, limits and causes of any soil changes associated with birch development on poor moorland soils. This paper summarizes the approach and the main findings to date, illustrating the latter by results from just one of the sites, situated near to Advie, Morayshire, in north-east Scotland (Fig. 1). Full details of the sites studied, methods and results, and critical discussion, will be given in a series of papers elsewhere.

METHODS

Any effects of a plant on the soil can only be demonstrated conclusively by experimentation, but with long-lived species like trees the time span necessary for such experiments is intimidating. Therefore, in order to obtain some preliminary evidence rapidly, we examined the soils under first generation birch stands of different ages and compared them with the soils of adjacent ground not colonized by birch. The main criterion for the selection of sites was the presence of birch invading a topographically uniform moorland area with a freely drained podzolic soil, also as uniform as possible. Thirteen sites were finally selected, situated from Spinningdale, Sutherland, in northern Scotland, to Silpho, North York Moors, in northern England (Fig. 1).

Two of the sites are old quarry floors in *Calluna* dominated moorland, three are felled *Pinus sylvestris* stands planted on former *Calluna* moorland, and the other eight are on *Calluna* moorland. *Betula pendula* grows at nine of the sites, and *B. pubescens* at three, while the remaining site has both species. The sites vary considerably in soil parent materials, elevation and aspect, but all lie in the relatively low rainfall areas of eastern Britain. The soils at all the sites are sandy and very low in clay, and also very low in bases, at least in the topsoil, except at one of the quarry sites.

The soil types of the uncolonized ground at the sites studied are as follows: podzol with mor humus

FIG. 1. — Location of sites.

at 6 sites; brown podzolic soil (sol ocre podzolique (DUCHAUFOUR, 1970)) with mor humus at 2 sites; brown podzolic soil with moder humus at 2 sites; old blanket peat (tourbière haute) with mor humus produced by a former stand of *Pinus sylvestris* at one site; skeletal soils (lithosols) at the 2 quarry sites.

There are clearly many possible pitfalls to interpreting the results from a comparative study like this. Soils characteristically show great variability (BECKETT & WEBSTER, 1971), often on a scale so small that a single tree can be rooted in two or more quite different soils (LYFORD, 1974). Few patches of heath or moor are effectively level, so soil catenas (chaînes de sols) are commonplace. The composition of the soil parent material can vary locally in drainage and base status, especially in transported materials like the glacial drifts found at most of the sites in this study, producing corresponding variations in the soil profiles developed. To this background of general soil variability must be added the fact that birch tends to colonise relatively fertile soils more readily, abundantly and vigorously than poorer soils (MILES & KINNAIRD, 1979). Therefore any birch wood soil is quite likely to be intrinsically more favourable to plant growth than soil on adjacent moorland.

To interpret the present differences in labile soil properties under moorland and adjacent birch stands as though they represented changes in time at a single point, it is necessary to determine the following:

1. That topography and relatively stable soil properties do not differ significantly between colonized and uncolonized moorland.
2. That the vegetation prior to birch colonization was the same as on the adjacent uncolonized ground.
3. That the birch stands are first generation.

If points 1 and 2 can be demonstrated, the presumption can be made that the labile soil properties did not differ significantly across the site before birch colonization began. Determining point 3 permits a time scale to be attributed to any inferred changes in labile soil properties simply by ageing the existing birch stand. The weak link in the argument is the premiss of antecedent similarity of labile soil properties, which cannot be tested. However, it was thought that if a fairly large number of sites were studied (with the intrinsic uniformity of each demonstrated as rigorously as possible), and showed the same trends in any inferred soil changes, then the premiss was likely to be valid.

Variability in stable soil properties was examined by studies of soil profiles, and of soil mineralogy and particle size distribution (granulométrie). These have defined the extent of variation across the sites, and have confirmed their effective uniformity in terms of relatively stable, plant-independent properties. For example, Figs. 2 and 3 give plots of the first and second components from principal component analyses of particle size distribution (7 variables), and stable profile characteristics (11 va-

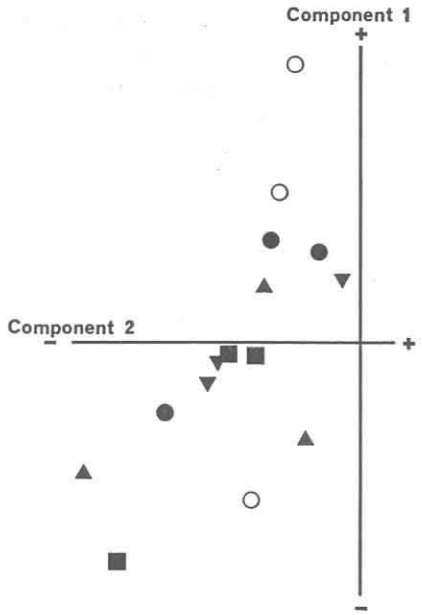

FIG. 2. — Plots of first and second components from a principal component analysis of soil particle size distribution at the Advie site. (Soil under *Calluna* ○, and *Betula pendula* aged 18 years ●, 26 years ■, 38 years ▼, and 90 years ▲).

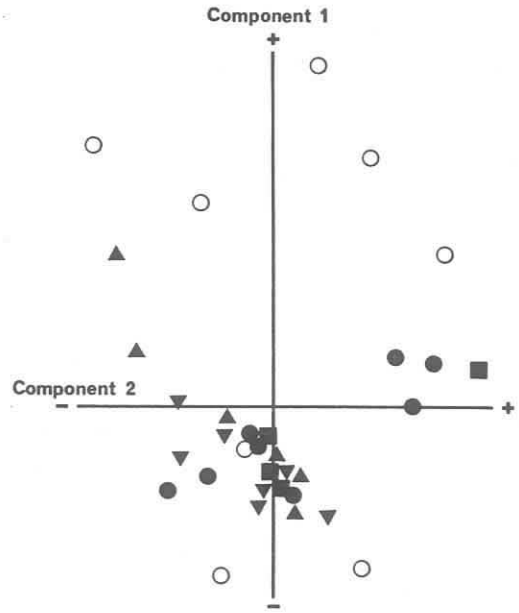

FIG. 3. — Plot of first and second components from a principal component analysis of stable soil profile characteristics (estimated by eye) from the C horizon at the Advie site. (Symbols as in Fig. 1).

riables) estimated by eye, respectively, from random points under *Calluna* and each age of birch at the Advie site. The trends represented by the axes are not important here. The salient fact is that although there is considerable scatter in both cases, points from the different age classes are completely intermingled, showing that intra-age class variability is greater than inter-age class variability. These results, together with similar evidence from mineralogical analysis, indicate the effective intrinsic uniformity of the soil across the site.

Evidence about the vegetation existing prior to birch colonization was obtained from examination of stem fragments of *Calluna,* and of the species and relative abundance of pollen and viable seed buried in the soil profiles. These provided unequivocal evidence that most of the birch stands examined at the 13 sites were definitely first generation, having colonized ground without birch.

In addition, the following measurements were made initially across all sites: (i) pH, bulk density, loss of weight on ignition and available-water capacity, on the top 5 cm of soil; (ii) N ammonium acetate extractable calcium, magnesium, potassium, sodium and hydrogen, 0.002N sulphuric acid extractable phosphorus, total carbon, nitrogen and phosphorus, rate of mineralization of nitrogen on incubation, loss of weight on ignition, and bulk density on the top 15 cm of soil. Additionally, 0-15 cm soil samples have been compared by assessing the growth in them of *Raphanus sativus* and other test plants under controlled glasshouse conditions. The extent of podzolization has been estimated by determination of 3 % oxalic acid extractable iron and aluminium down the profiles. Rates of cellulose decomposition have been studied at two sites using cotton strips following the method of LATTER & HOWSON (1977), and earthworm populations have been estimated at one site. Latterly, measurements have concentrated on examining the processes of soil change under birch. They have included descriptions of birch root systems, of total, exchangeable and potentially mobilizable bases down soil profiles, and of the tannin contents of birch leaves. Changes in the ground vegetation under birch canopies have also been investigated.

RESULTS

Since birch colonization began, substantially the same trends seem to be evolving at all sites, although the extent and rate of change varies considerably between sites. (Tables 1 and 2 show some of the trends in vegetation and soil respectively for the site near Advie, Morayshire).

The vegetation changes are:

(a) Gradual death of the *Calluna* ground-cover as birch canopies develop, and its replacement by *Deschampsia flexuosa* and *Vaccinium myrtillus* in particular, the former especially on more mineral soils, the latter where an organic surface horizon is better developed.

(b) Gradual appearance of species characteristic of woodlands and grasslands e.g. *Agrostis spp., Anthoxanthum odoratum, Hypericum pulchrum, Oxalis acetosella, Viola riviniana,* as soil conditions change, and a decrease in the numbers of species characteristic of *Calluna* heath. It has been found experimentally that species like *Primula vulgaris, Prunella vulgaris* and *Viola riviniana* are unable to establish from seed on bare soil in *Calluna* heath, but survive on soils in birch stands aged *c.* 25-40 years.

TABLE 1

Changing numbers of vascular plant species found in Calluna *heath and adjacent stands of* Betula pendula *aged from 18 to 90 years old, near Advie, Morayshire, Scotland*

	Age of stands of *B. pendula*				
	Calluna heathland	18 years	26 years	38 years	90 years
Number of species present as growing plants	12	20	19	24	30
* Total number of species present	16	24	23	28	33
* Total number of heathland species absent from the woodland	–	2	3	4	7
* Total number of species present in the woodland not occurring in the *Calluna* heathland	–	11	11	15	25

* Includes species present only as buried, viable seed – an important part of any flora.

The main trends in soil change in the top 15 cm are:

(a) A gradual change in the composition of the buried seed flora to one characteristic of woodland, following changes in the field layer; soil pollen accumulations changed similarly.

(b) A considerable increase in numbers of surface living earthworms, especially *Lumbricus rubellus,* and with *Lumbricus terrestris* and *Allolobophora spp.* appearing later as soil conditions change.

(c) A gradual breakdown of the old *Calluna* mor humus layer and its conversion to a mull-like form, probably due largely to earthworm feeding.

(d) Increased rates of cellulose decomposition and of nitrogen mineralization.

(e) A decrease in exchangeable hydrogen, and increases in pH, exchangeable calcium and total phosphorus.

(f) A decrease in carbon/nitrogen, carbon/phosphorus and carbon/potassium ratios from the critical levels present on the moorlands (*c.* 20-30, 350-500 and 400-500 respectively) at which nutrient immobilization and deficiencies would be expected (EVERS, 1967; GOSZ *et al.,* 1973; DOWDING, 1974).

(g) Increasing growth response of test plants in glasshouse trials.

In addition, there is a suggestion that the bleached Ea horizon in podzols is being gradually obliterated by the incorporation of organic matter and ferric iron, thus tending to form brown podzolic profiles, and also that the boundary between the B and the Ea or A horizons is becoming less sharp. Also there was an apparent decrease in exchangeable

TABLE 2

Soil analyses from Calluna *heathland and nearby stands of* Betula pendula, *aged from 18 to 90 years old, near Advie, Morayshire, Scotland*

		Age of *B. pendula* stands				
	Calluna heathland	18 years	26 years	38 years	90 years	Least significant difference at 5 % level
* pH	3.8	3.9	4.0	4.7	4.9	0.1
** Exchangeable H (mg dm^{-3})	117	108	109	101	89	25
** Exchangeable Ca (mg dm^{-3})	196	201	207	489	319	83
** Total P (mg dm^{-3})	151	210	196	240	232	82
** N mineralization after 14 days 14 days incubation (mg dm^{-3} $week^{-1}$)	− 1.3	25	41	45	40	10
** C/N ratio	30	26	19	22	15	11
** C/P ratio	500	320	280	270	170	200
** C/K ratio	440	430	410	460	310	210
** Bioassay : mean shoot dry weight (mg) of 8 weeks old *Raphanus sativa*	8.7	18	43	59	6	18
Mean number of earthworms per 1 m^2 (by formalin extraction)	1	5	27	127	78	26

* Soil from 0-5 cm, after removing L + F layer.
** Soil from 0-15 cm, after removing L + F layer.

calcium beneath 90 year old birch at the Advie site and at another site with equally aged birch.

Studies to elucidate the mechanisms involved in these soil changes are still proceeding and most of the data have yet to be analysed in detail. No results will be presented here therefore, but the work is briefly mentioned later.

DISCUSSION

VALIDITY OF THE INTERPRETATIONS.

As soil conditions before birch colonization began can never be determined conclusively, evidence from a survey made at a single point in time must be interpreted cautiously. In particular, the inferences drawn about the effects of birch may be confounded with the effects of slope at certain of the sites (including Advie). Ground water movements can prevent podzolization (TAMM, 1950), and soil creep may do also (MUIR & FRAZER, 1940). However, whether or not actual depodzolization (that is, obliteration of the eluviated Ea or A_2 horizon) eventually occurs, the results suggest that under developing birch there is a trend in labile soil properties towards those characteristically associated with brown podzolic soils, the formation of mull humus and increasing pH and microbial activity in particular. This was the trend at all sites, including the two quarries where soil development was on virgin substrata and antecedent similarity is not in question.

PROCESSES OF CHANGE.

The death of *Calluna* below the developing birch canopies seems to be by natural senescence, perhaps accelerated by the effects of shading. The field layer is too dense to permit *Calluna* to re-establish from seed even though large numbers of viable seeds are present in the soil.

The sharp increase in nitrogen mineralization rate from under *Calluna* to 18 year old birch probably reflects the change in the organic substrate from *Calluna* to mainly birch litter. The particularly marked increases in pH and exchangeable calcium of topsoil under 38 year old birch probably reflect in part a temporarily enhanced rate of calcium input from lower branches shed after canopy closure. The downward trend in exchangeable calcium under 90 year old birch, and possibly also in nitrogen mineralization rate, suggests a cyclic trend, in the opposite direction to that apparently found under certain conifers (PAGE, 1968, 1974). This might be expected as a consequence of the birch life cycle, where a stand develops a closed canopy and matures, with litter fall reaching a peak, and then opens up with tree senescence and death, often allowing *Calluna* to re-invade.

The work has raised many questions. Two in particular are being investigated. Firstly, what is the origin of the increased amounts of exchangeable calcium found in the topsoil of relatively old stands of birch? Through its effect on pH, and thus on the soil microflora and fauna, this calcium seems to be critically involved in the change from mor to mull. Initially it was hypothesized that as birch roots more deeply than heather, it may be absorbing calcium at greater depths than heather can. However, while this is currently being investigated by radiotracer studies, other evidence coming to hand suggests that birch is also accelerating the weathering of soil minerals compared with under heather, especially in the topsoil.

Secondly, if depodzolization does occur under birch, how is the Ea horizon obliterated? Mobilization of iron through the birch trees would appear to have only a small effect, and soil mixing is probably the major cause, with surface organic matter being mixed downwards, and B horizon soil upwards. If this is so, to what extent can this be attributed to earthworms, other soil living animals (e.g. ants) and to the growth of roots? Fairly rapid depodzolization through soil mixing seems quite feasible. The upland podzols examined in this study characteristically have shallow Ea horizons, commonly less than 10 cm thick. It is doubtful however if the deeper Ea horizons commonly found in podzols further south could be so readily destroyed, for example those of the Lorraine Plateau or Vosges hills (GUILLET, 1970, 1971), or those of the Bagshot district of southern England, with Ea horizons commonly 50-100 cm or more in depth.

To verify the soil changes inferred from this survey, and to elucidate further the mechanisms involved, a series of long term experiments is currently being established. Birch is being planted at three *Calluna* heath sites on shallow podzols, and *Calluna* is being established after felling birch wood at three sites with brown podzolic soils.

POSSIBLE IMPLICATIONS FOR FORESTRY PRACTICE.

The results of this study give a new impetus to questions that have often been raised about the long term consequences of growing extensive conifer monocultures. Evidence suggests that some conifers, especially *Picea* and *Pinus* spp., cause surface acidification and accelerate podzolization (MILES, 1978), in contrast to birch. Substantial areas of Europe, where soils developed largely under natural broadleaved woodlands, have now been replanted with conifers, and are therefore liable to soil acidification and to accelerated podzolization on susceptible soils. In Czechoslovakia for example, MARZHAN (1959) has estimated that up to 0.4 Mha are podzolizing under *Picea abies* and *Pinus sylvestris*.

Because podzols are generally associated with poorer volume growth of trees, even of species

adapted to such conditions, than are brown podzolic and other brown soils (LÅG, 1962; PYATT, 1970; PAGE, 1971), it might be expected that soil changes under conifers would eventually cause declining yields. The evidence is equivocal however. Whereas some studies have indicated slower growth rates of second generation stands of conifers at some sites (SIREN, 1955; KEEVES, 1966; WHYTE, 1973), others have been unable to detect changes (GENSSLER, 1959; HOLMSGAARD *et al.*, 1961; HAUSSER, 1964; BUBLINEC, 1973). Conversely, it might be expected that depodzolization would be associated with increasing yields. Certainly the faster rates of decomposition and nutrient release associated with birch and other broadleaved trees in mull-forming systems would be expected to accelerate plant growth. Therefore, would an admixture of broadleaved trees benefit the growth of conifers? There have been claims to this effect (SHUMAKOV, 1958; KOVALEV, 1969; BLINTSOV, 1971; PRUDIC, 1972), but the supporting data are unconvincing. Thus, despite the marked soil changes that occur under many species, it is still an open question whether these have any effects, positive or negative, on timber yields. The value of pure conifer versus mixed conifer-hardwood stands clearly needs critical evaluation.

In this context it should also be remembered that in natural conditions soils are commonly subject to a succession of tree species (MILES, 1979), while indeed in boreal regions like much of the Scottish Highlands, conifers and broadleaved species tend to alternate. Such changes will keep decomposition systems in a similar state of flux, and in the latter case will have tended to effect an alternation between mor-forming and podzolizing, and mull-forming and possible depodzolizing plant/soil systems, thereby maintaining a long term balance. Therefore, as well as the advisability of mixed stands, should we also be considering rotations of species in these plantations ? Or has their need been removed by current forestry technology, in particular the ubiquitous use of ploughing and the increasing use of fertilizers ? The answers are unknown. We have no idea how forestry management techniques for maintaining soil fertility compare with natural processes. Yet the need to spend increasing sums on fertilizers whose manufacture is energy-demanding surely justifies a thorough investigation of this subject.

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